

GAUGING THE OPERATIONAL VALUE OF NAVAL INFRASTRUCTURE

The Case of Surface Combatant Manning

Presentation to

**The Second Annual Navy Manpower,
Personnel, and Training Research and
Analysis Conference**

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BACKGROUND

- **THE NAVY HAS RECENTLY BEGAN ASKING HARD QUESTIONS ABOUT NAVAL INFRASTRUCTURE**
 - **What is the Military Value of Infrastructure?**
 - **How to Gauge Effect of Investments in Infrastructure upon the Navy's Warfare Capability**
- **THESE QUESTIONS ARE DRIVEN BY A NUMBER OF DIFFERENT SPECIFIC CIRCUMSTANCES**
 - ***Military:* Perceived Imbalance Between Structure and Infrastructure**
 - ***Financial:* No Money to Buy Enough of Both**
 - ***Administrative:* The Navy's IWAR Process**
- **TO ANSWER, ONE NEEDS TO QUANTITATIVELY CONNECT STRUCTURE AND INFRASTRUCTURE**

THE UNDERLYING DIFFICULTY

- **WARFIGHTING AND SUPPORT COMMUNITIES ARE NOT MEANINGFULLY CONNECTED TO EACH OTHER**
 - **Warfighting Community Focuses on Platforms and Systems, and Assumes Infrastructure Will be There**
 - **Support Community Focuses on Management, and Assumes Infrastructure Will be Useful**
- **EVEN DEFINITION OF INFRASTRUCTURE CURRENTLY IN USE NO LONGER POINTS TO ITS MILITARY VALUE**
 - **Either Characterized by Features Irrelevant to Warfighting, Such As Its Relation to Land**
 - **Or Reduced to a Mere Listing of Activities that Attempts to Be Neither Prioritized Nor Complete**

THE GUIDING IDEA

- **INFRASTRUCTURE IS THE SET OF ACTIVITIES THAT PRODUCES A NATION'S MILITARY STRUCTURE**
 - ***Acquisition:*** Procures a Structure that is Ready for Operational Employment
 - ***Maintenance:*** Ensures the Structure Remains So
 - ***R&D:*** Adjusts Structure to Changing World
- **THEREFORE, EACH STRUCTURE COMPONENT, BE IT MAN OR EQUIPMENT, HAS DOUBLE CHARACTER**
 - ***As Instrument of War*** It Contributes to Warfare
 - ***As Product of Infrastructure*** it Reflects Quality of Activities that Contributed to its Production
- **THIS OPENS THE WAY TO CONNECTING WARFARE CAPABILITY WITH QUALITY OF INFRASTRUCTURE**

ANALYTIC APPROACH

- **IN TIME OF PEACE, WARFARE CAPABILITY IS OFTEN ESTIMATED BY APPROPRIATE WARFARE MODELS**
 - **They Relate Warfare Capability to Inputs of Systems Performance and Human Proficiency**
 - **These Inputs are Numbers Usually Taken Either from Engineering Studies or from Fleet Data**
- **BUT, ALL INPUTS SHOULD BE FUNCTIONS OF INFRASTRUCTURE ACTIVITIES INVOLVED, NOT NUMBERS**
- **THEREFORE, WE MUST RELATE ALL MODEL INPUTS TO THEIR RELEVANT INFRASTRUCTURE ACTIVITIES**
 - ***Performance Inputs:* R&D, Production, Repair**
 - ***Proficiency Inputs:* Recruitment, QOL, Training**

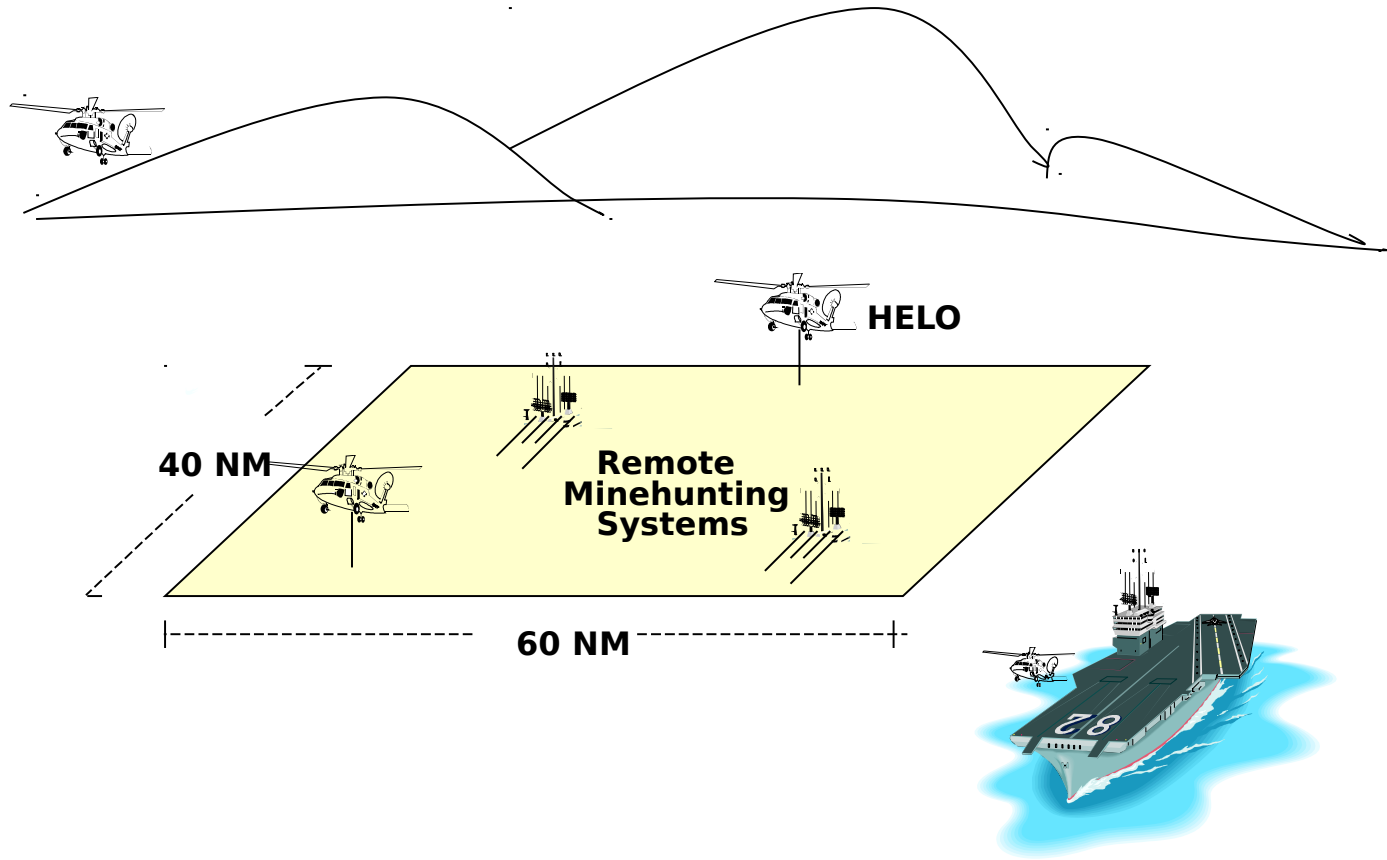
TESTING THE APPROACH

- **THE APPROACH CAN BE IMPLEMENTED**
 - **We Show that Approach can Relate Mission Effectiveness to Infrastructure Activities**
 - **Illustration: Organic Mine Countermeasures in Preparation for CV Operations**
 - **Illustration: Manning of Surface Combatants**
- **THE APPROACH CAN AID DECISION MAKERS**
 - **We Show that Approach Offers a Means of Trading Between Investments in Structure an Investments in Infrastructure Activities**
 - **Illustration: Should the Navy Build a Shallow Water ASW Training Range?**

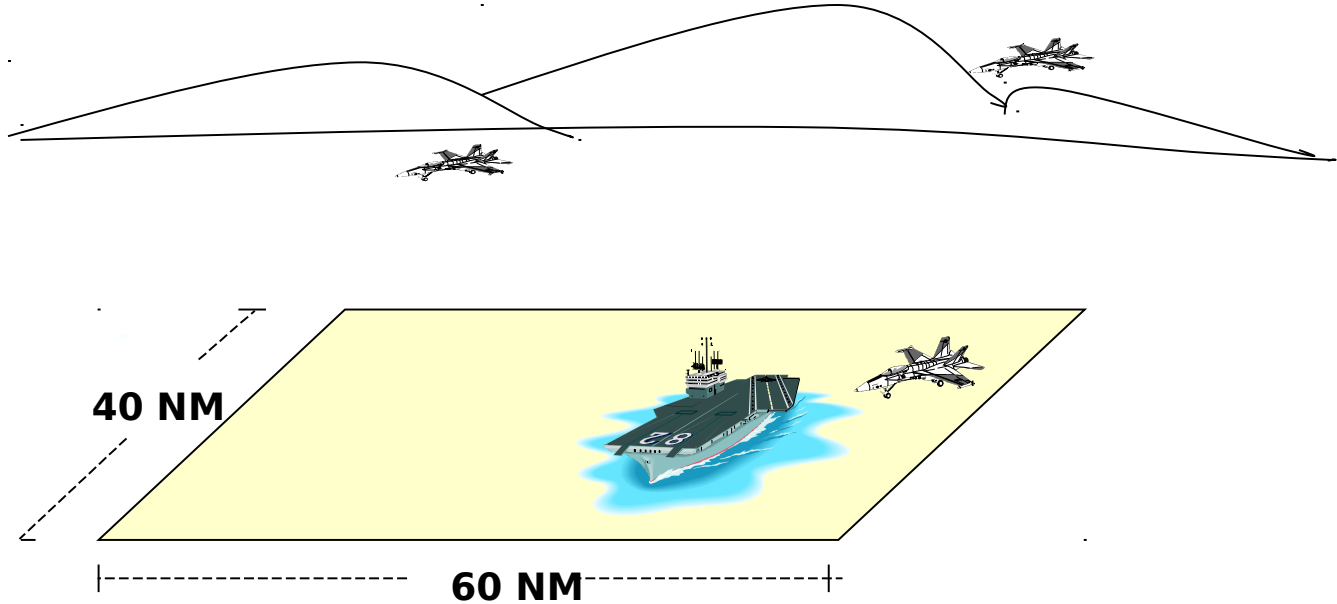
**SHOWING THAT THE APPROACH
CAN BE IMPLEMENTED**

***MODELING ORGANIC MINE
COUNTERMEASURE OPERATIONS***

MINEHUNTING OPERATION



CARRIER STRIKE OPERATION



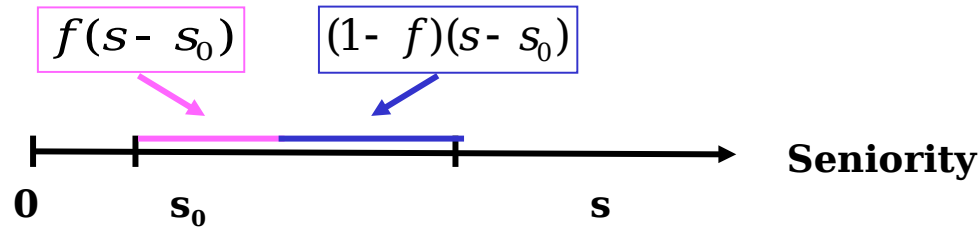
IMPLEMENTING THE APPROACH

- **OPERATIONAL EFFECTIVENESS IS MEASURED BY PROBABILITY THAT CARRIER DOESN'T HIT A MINE**
- **MODEL INPUT IS THE PROBABILITY THAT POST-MISSION ANALYST CORRECTLY IDENTIFIES MINE**
- **INFRASTRUCTURE ACTIVITIES CAPTURED**
 - **Realistic Training of Post Mission Analysts**
 - **Quality of Life Affecting their Retention**
- **PARAMETERS CHARACTERIZING THE ACTIVITIES**
 - **Frequency of Realistic Training Opportunities**
 - **Retention Probability**

MODELING INDIVIDUAL PROFICIENCY

- **PROFICIENCY CHANGES DUE TO THE INTERPLAY BETWEEN LEARNING AND FORGETTING**
 - **When the Operator is Exercising his Skills,
Proficiency Increases as a Result of Learning**
 - **When the Operator is not Exercising his Skills,
Proficiency Decreases as a Result of Forgetting**
- **WE ASSUME THAT THE RATE OF INCREASE IS**
 - **Proportional to Current Level of Proficiency**
 - **Inverse Proportional to Length of Time the Operator Employed Skills since Last**

ILLUSTRATIVE SOLUTION

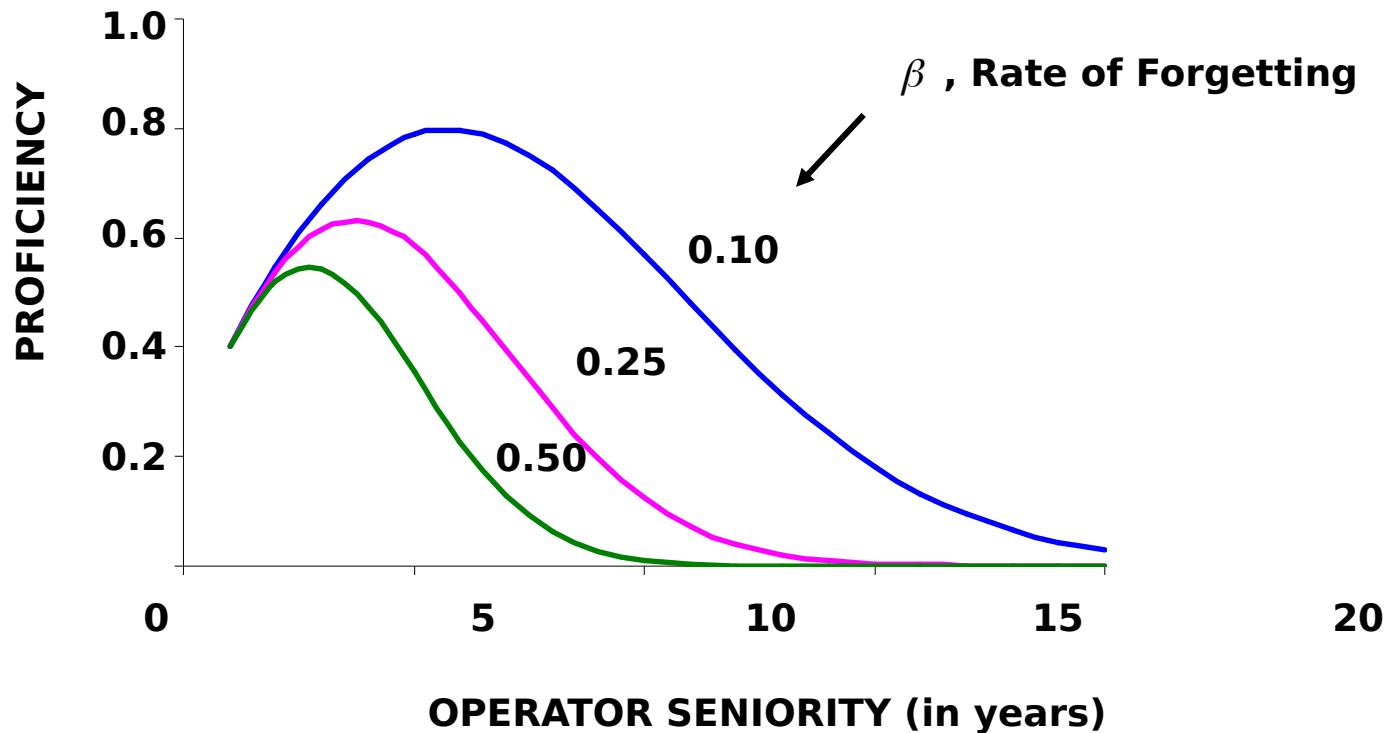


$$\frac{d\phi}{ds} = \frac{\alpha f \phi(s)}{s_0 + (s - s_0)f} - \beta (1 - f)(s - s_0)(1 - f)\phi(s)$$

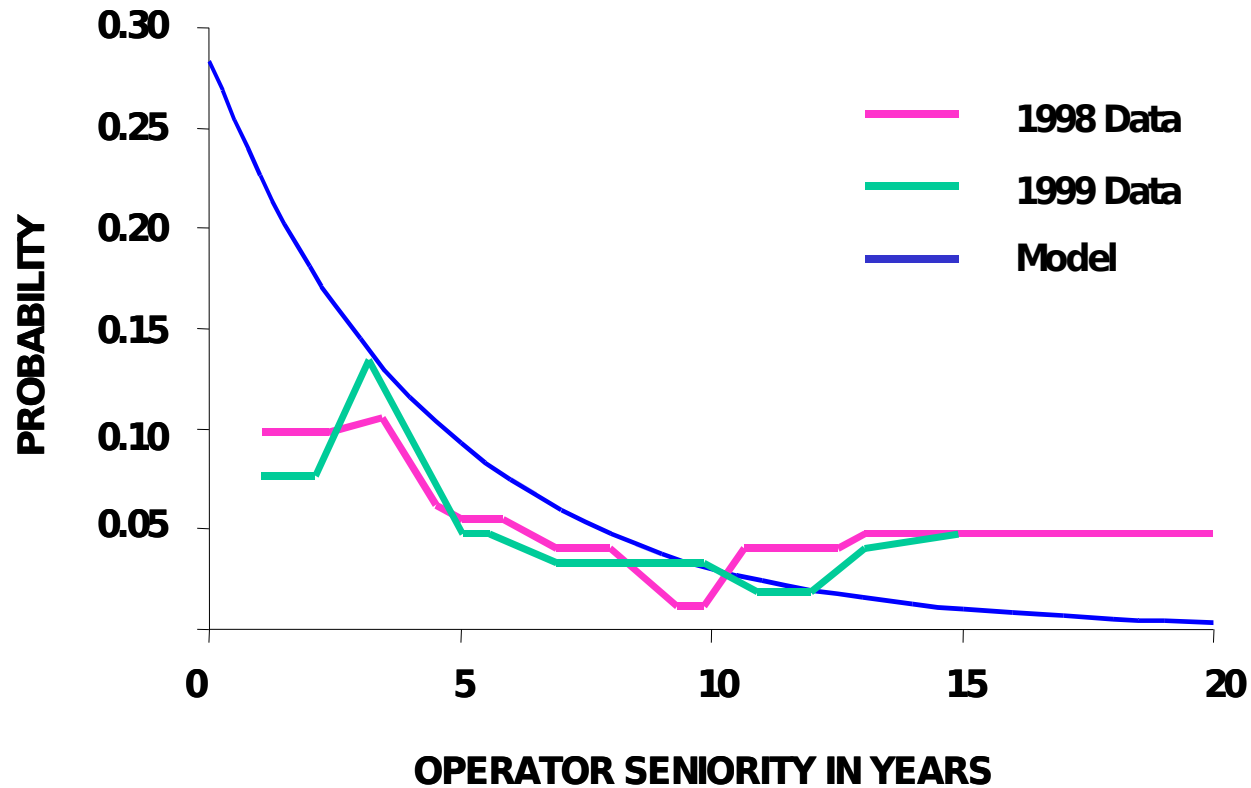
$$\phi(s) = \phi(s_0) \left(1 + \frac{s - s_0}{s_0} f\right)^\alpha e^{-\frac{1}{2}\beta(1-f)^2(s-s_0)^2}$$

EFFECT OF OPERATOR SENIORITY

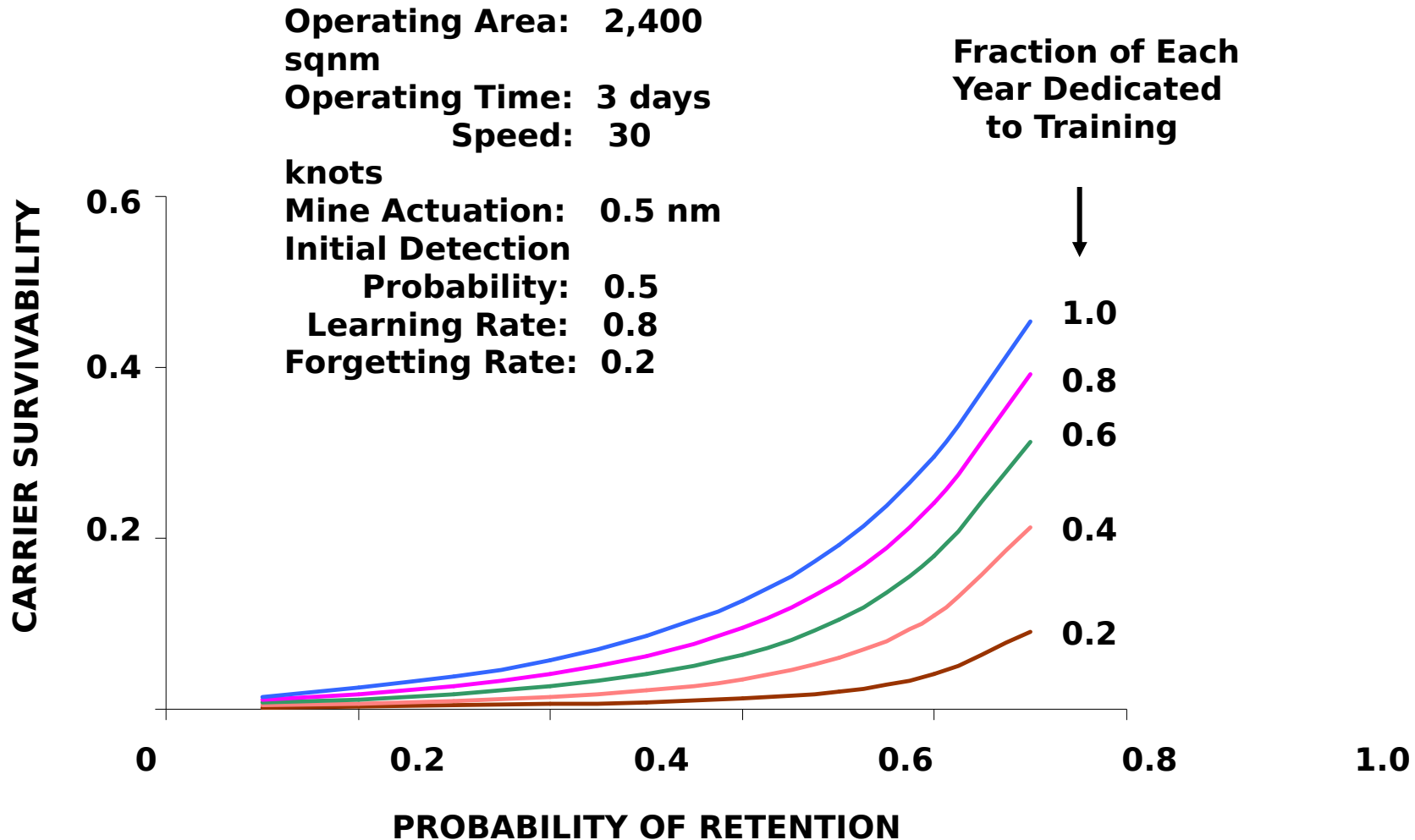
α , Rate of learning = 0.8



THE SENIORITY DISTRIBUTION



OPERATIONAL EFFECTIVENESS



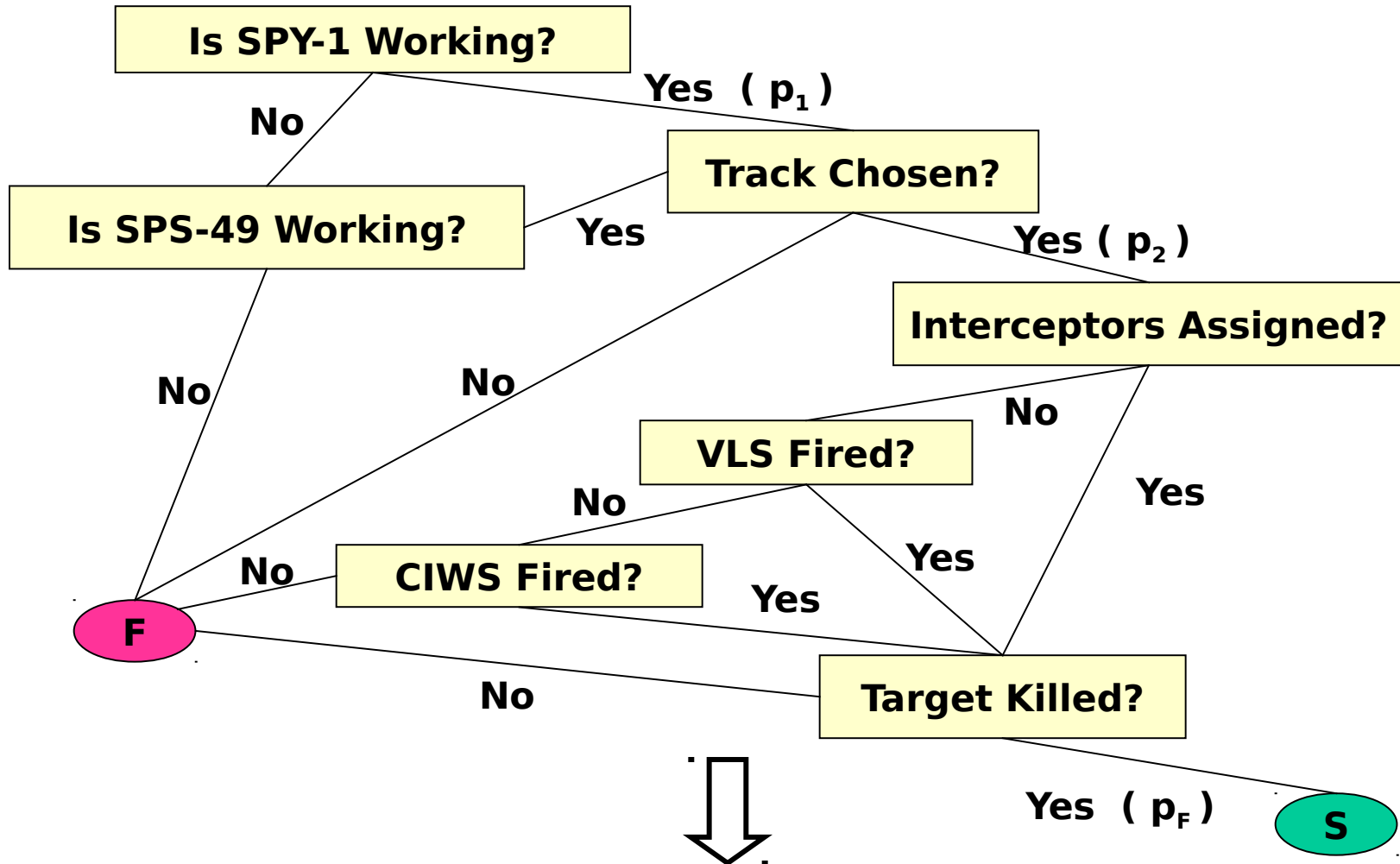
**SHOWING THAT THE APPROACH
CAN BE IMPLEMENTED**

***HOW MANY SAILORS TO MAN
A SURFACE COMBATANT?***

IMPLEMENTING THE APPROACH

- **OPERATIONAL EFFECTIVENESS IS MEASURED BY PROBABILITY OF SUCCESS IN PERFORMING AAW**
- **MODEL INPUTS ARE THE PROBABILITIES THAT SAILORS SUCCESSFULLY COMPLETE FUNCTIONS**
- **THESE INPUTS ARE DETERMINED BY AT LEAST THE FOLLOWING INFRASTRUCTURE ACTIVITIES**
 - **Realistic Training of Each Sailor**
 - **Quality of Life Affecting his Retention**
 - **Training of Ship's Crew**
- **THESE ACTIVITIES WILL BE DESCRIBED BY**
 - **Frequency of Realistic Training Opportunities**
 - **Retention Probability**
 - **Crew Cohesion and Leadership Quality**

FUNCTIONAL STRUCTURE FOR AAW



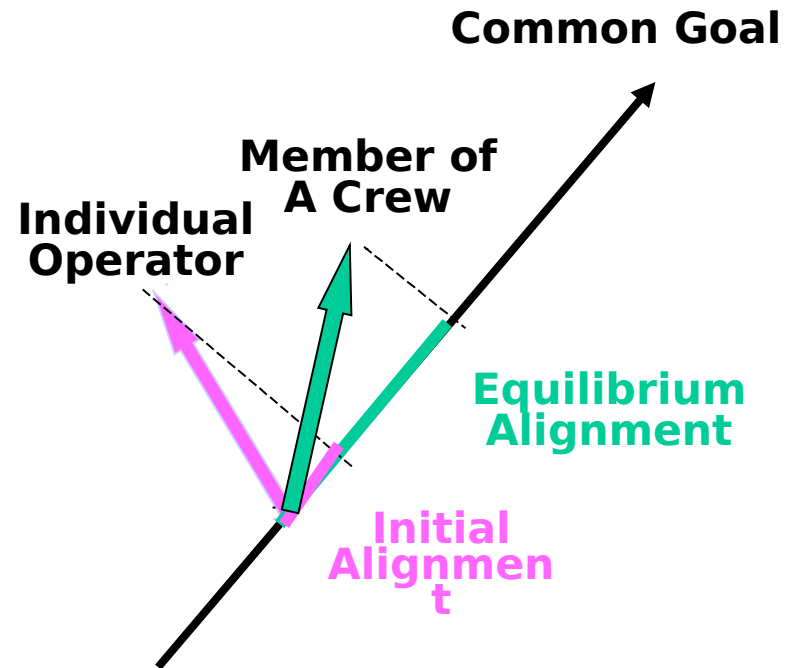
$$\text{Pr (Mission Success)} = \mu (p_1, p_2, \dots, p_{F-1}, p_F)$$

THE HUMAN FACTOR

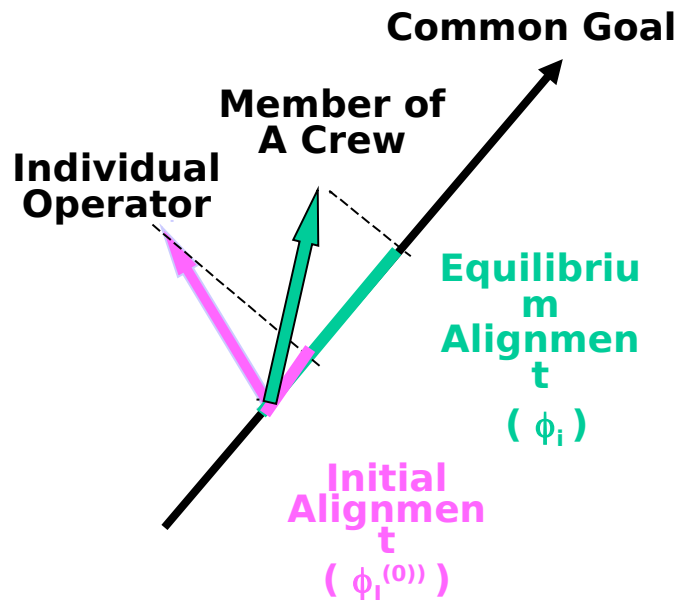
- **THERE IS NO ALLOWANCE HERE FOR HUMAN PERFORMANCE THAT IS SHORT OF PERFECT**
- **IN REALITY, HUMAN PERFORMANCE WOULD DEGRADE ALL ENGINEERING VALUES $p_i^{(eng)}$**
- **WE SHALL THEREFORE REPLACE EACH $p_i^{(eng)}$ BY $H_i \cdot p_i^{(eng)}$ WHERE THE FACTOR H_i CAPTURES**
 - **Reduction due to Individual Proficiency as a Function of Operator Seniority and Training**
 - **Enhancement of that Proficiency Induced by Crew Cohesion and Command Leadership**
 - **Reductions Induced by Excessive Time on Watch as Function of Ship's Company**

MODELING CREW ENHANCEMENT

- **CREW IS GENERALLY MORE PROFICIENT THAN TOTALITY OF ITS MEMBERS BECAUSE**
 - **Need to Contribute to the Common Goal Induces an Organizing Tendency that Makes Each Crew Member More Proficient (Cohesion)**
 - **Leadership Reduces the Disorganizing Tendencies Generated by Individuality of its Members**
- **THE CREW REACHES ITS FULL POTENTIAL WHEN THESE TWO FORCES ARE BALANCED**



MODELING CREW ENHANCEMENT



g Order Parameter
 h Disorder Parameter
 $(1 - \phi_i)$ Misalignment
 B Intensity of the Organizing Force

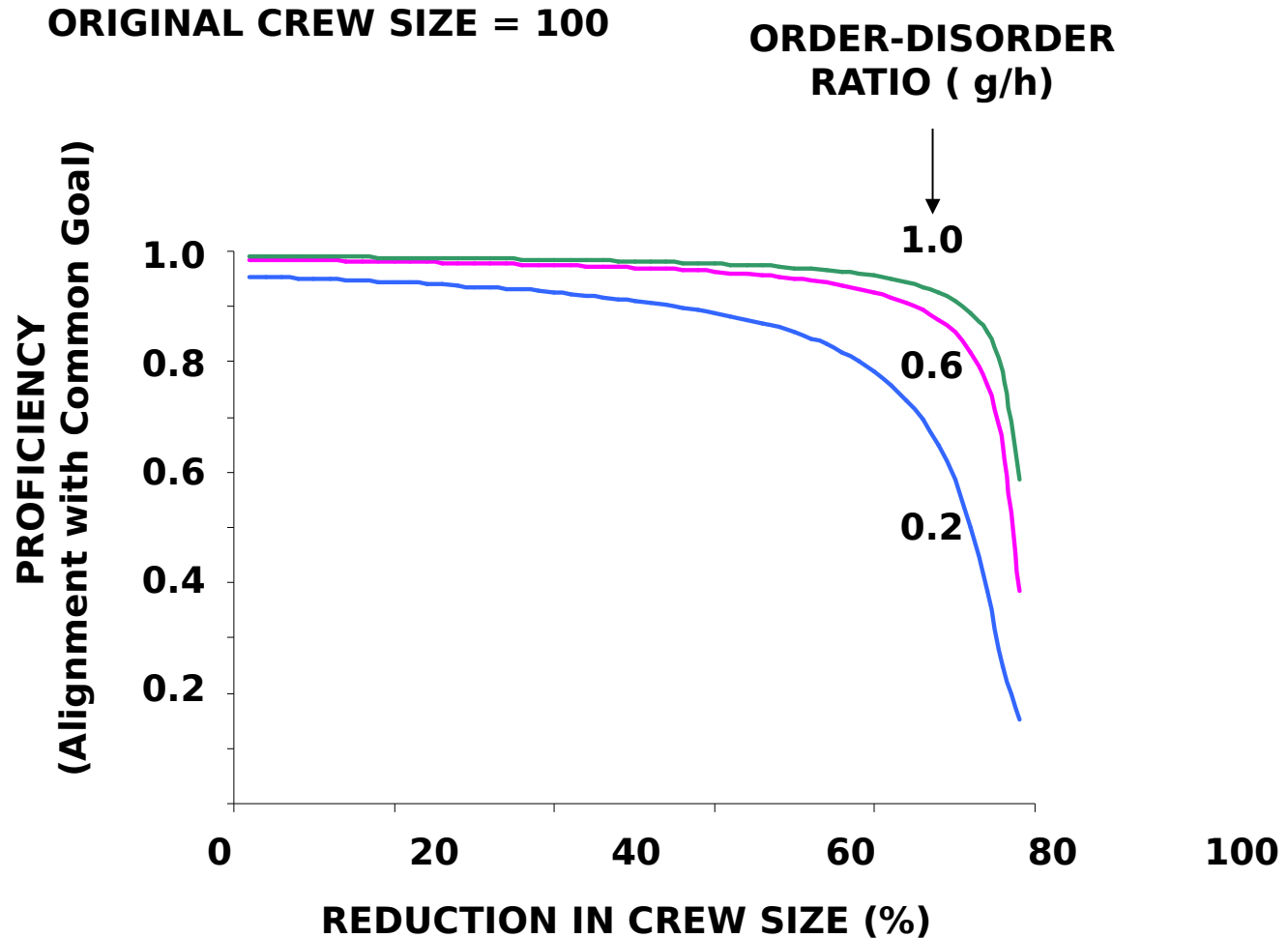
$$\text{Organizing Force} = gB(1 - \phi_i)$$

$$\text{Disorganizing Force} = h(\phi_i - \phi_i^{(0)})$$

$$gB(1 - \phi_i) = h(\phi_i - \phi_i^{(0)})$$

$$B = \sum_{i=1}^F \phi_i$$

DIMINISHING CREW SIZE



THE EFFECTS OF WATCH-STANDING

- **PERFORMANCE AT A WATCH STATION DEPENDS ON NATURE OF WATCH-STANDING OPERATION**
- **IF STATION IS MANNED IN SHIFTS, PROFICIENCY DROPS EXPONENTIALLY WITH TIME ON STATION**
 - **Time on Station Decreases in Direct Proportion With Number of People Assigned to Function**
 - **The Exponent Increased by Adverse Conditions Prevailing at the Watch Station, such as Noise, Heat, Traffic, and General Disorder in the Area**
- **IF MANNED UPON REQUEST, QUALITY OF SERVICE DEPENDS UPON NUMBER OF PEOPLE ON STATION**
 - **Likelihood of a Response Increases, but**
 - **Proficiency of each Respondent Decreases**

MEASURE OF PERFORMANCE

- FOR EACH DISTRIBUTION $\{n_i\}_{i=1...F}$ OF PEOPLE OVER FUNCTIONS EVALUATE:

$$\Pr(\text{Mission Success}|\{n_i\}) = \mu [H_1(g/h, n_1, \lambda_1)$$

$p_1^{\text{eng}},$

$$H_2(g/h, n_2, \lambda_2) p_2^{\text{eng}}, \dots, H_F(g/h, n_F, \lambda_F) p_F^{\text{eng}}$$

- ~~1~~ MAXIMIZE THIS CONDITIONAL PROBABILITY OVER ALL DISTRIBUTIONS $\{n_i\}_{i=1...F}$ FOR GIVEN VALUES F
- MEASURE PERFORMANCE BY THE RESULTING OPTIMAL PROBABILITY AS A FUNCTION OF F

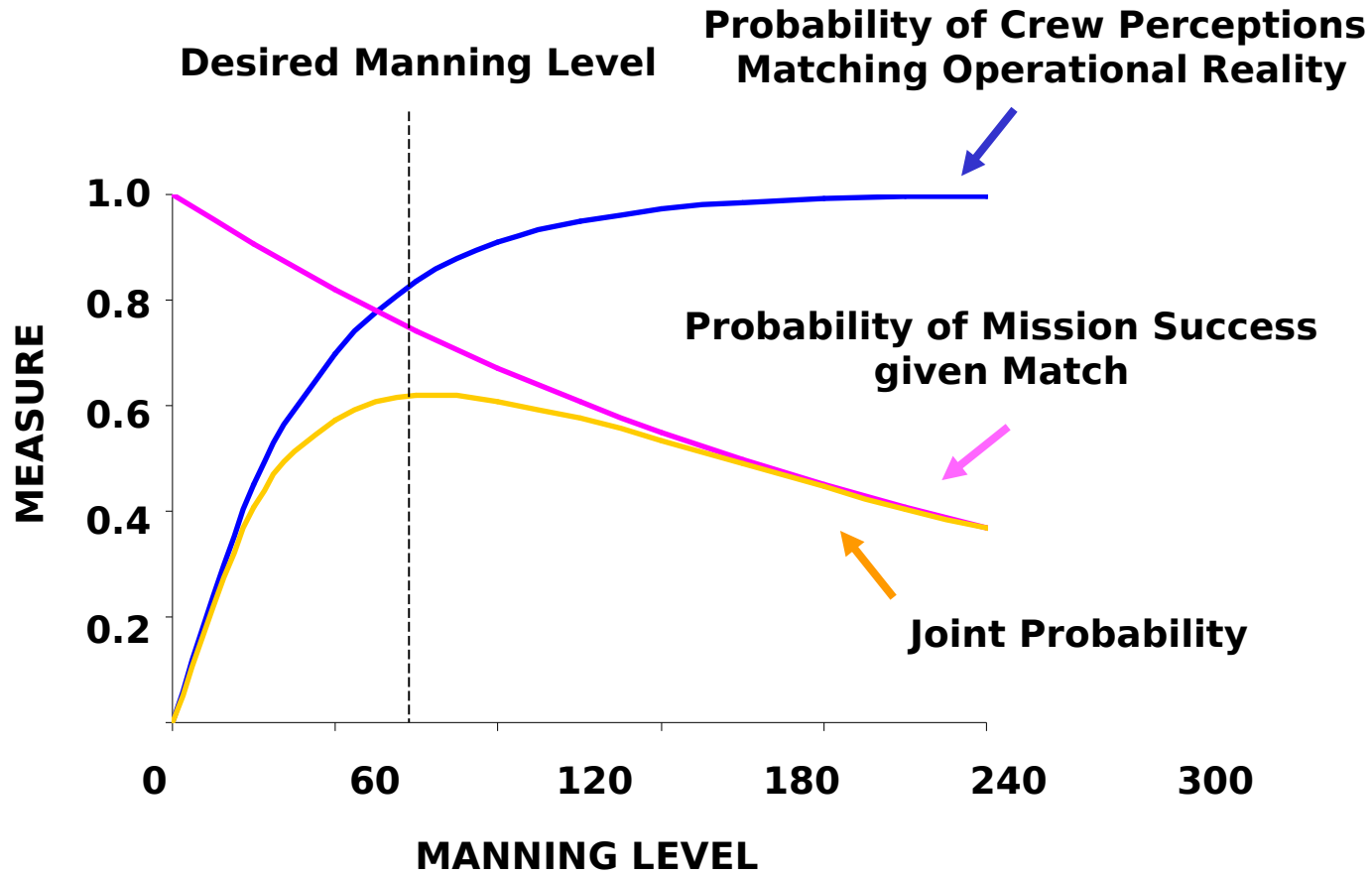
RISK OF AUTOMATION

- **SINCE MACHINES FUNCTION BETTER THAN MEN**
 - **Human Factor H is Generally Less than One**
 - **Replacing Humans with Machines would Raise Proficiency from $H \cdot p_{eng}$ to p_{eng}**
 - **One Might Want to Automate All Functions**
- **HOWEVER, IF THE SITUATIONAL ASSUMPTIONS MADE BY THE CREATOR WERE NOT ACCURATE,**
 - **What Machines Do will not Necessarily Match with the Prevailing Situation and their Action Might Prove to be Counterproductive**
 - **Unlike Humans, Machines will not be Able to Correct the Situation in Time to Matter**
- **THEREFORE, AUTOMATING ALL SHIP FUNCTIONS WOULD REDUCE OVERALL PERFORMANCE**

SEEKING PROPER CREW SIZE

- **AS SHOWN ABOVE, AUTOMATION TENDS TO**
 - **Increase Ship Performance by Replacing Men with Faster, More Accurate Machines, though Crew Behavior may Mitigate that Somewhat**
 - **Decrease Ship Flexibility by Replacing Men with Less Adaptable, Less Robust Machines**
- **THUS, REDUCING MANNING BY AUTOMATING MORE FUNCTIONS SHIFTS BALANCE BETWEEN**
 - **Ship's Operational Performance as Measured by Probability of Mission Success Optimized over $\{n_i\}_{i=1...F}$ for a Specified Manning Level F**
 - **Ship's Operational Flexibility as Measured by Probability of a Match Between the Crew's Perceptions and Operational Reality Given F**
- **SEEK THE MANNING LEVEL F THAT BALANCES MISSION EFFECTIVENESS WITH FLEXIBILITY**

BALANCING PROCESS



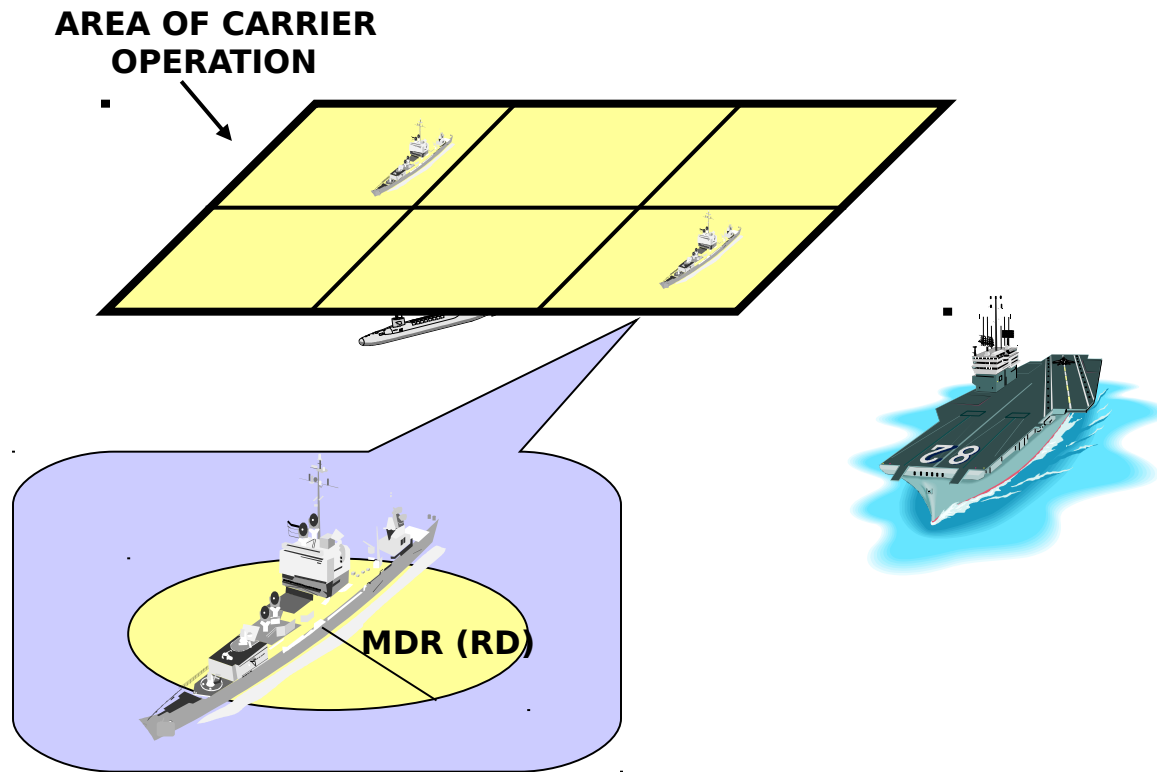
**SHOWING THAT THE APPROACH
CAN AID DECISION MAKERS**

***SHOULD THE NAVY BUILD A SHALLOW
WATER ASW TRAINING RANGE?***

THE TRAINING RANGE ISSUE

- **THERE ARE THREE KEY ISSUES THE NAVY MUST SETTLE BEFORE A DECISION COULD BE MADE**
 - **Will Ranges Conform to Environmental Regulations Prevailing in the Area?**
 - **Will Sonar Operator Schedules Allow Full Exploitation of these Facilities?**
 - **Is Investment in these Ranges Justified by the Increased Operational Capability?**
- **TO ANSWER THE LAST QUESTION, WE CONNECT CAPABILITY TO TRAINING IN PRECURSOR ASW**

PRECURSOR ASW OPERATIONS



IMPLEMENTING THE APPROACH

- **OPERATIONAL EFFECTIVENESS IS MEASURED BY PROBABILITY THAT SUBMARINE FAILS TO HIT CV**
- **MODEL INPUT IS RECOGNITION DIFFERENTIAL**
- **INFRASTRUCTURE ACTIVITIES CAPTURED**
 - **Initial Training at ASW Operator School**
 - **Subsequent Training in Shallow Water ASW**
- **PARAMETERS CHARACTERIZING THE ACTIVITIES**
 - **Recognition Differential at Graduation**
 - **Frequency of Realistic Training Opportunities**

THE TRADE-OFF PROCESS

